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CIRCULAR STRUCTURES ON EARTH AND ON THE PLANETS

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CIRCULAR STRUCTURES ON EARTH AND ON THE PLANETS

L. M. Shkerin[1]

ABSTRACT. The features of the formation of circular structures on Earth (of volcanic, meteoritic, and nuclear origin) are examined in an effort to determine the possible origin of similar structures on the Moon and inner planets.

The magazine "Priroda" (No. 9, 1969) recently carried an article by /55* I. T. Zotkin, entitled "Lunar Craters on Earth," in which the author expressed his viewpoint regarding the cosmic origin of the crater-like formations on the lunar surface. Many scientists share this opinion. On the other hand, there are many round structures on our planet which are well-known, and which owe their origin to internal (endogenic) processes. For this reason, investigators (especially geologists) felt justified in suggesting that the crater-like structures on the Moon and Mars have an origin similar to that of those on Earth. A conclusive answer to this question would make a considerable contribution to the understanding of the development not only of the inner planets but of the entire solar system.

On the Moon, On Mars and On the Earth

In 1609-1610 Galileo was the first to sketch the lunar circular mountains. It was found later that the circular structures that resemble the craters of volcanoes on Earth constitute the principle feature of the relief of the visible visible side of the Moon. The diameters of the large craters (walled plains) reach 200-300 km, while the larger circular structure (Mare Imbrium) is 1,150 km in diameter. On October 7, 1959 the automatic interplanetary station "Luna-3" made the first pictures of the hidden side of the Moon. It was found that the latter is strewn to an even greater extent with craters of different sizes.

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*Numbers in the margin indicate pagination of the foreign text.

On July 15, 1965 the American Automatic Interplanetary Station "Mariner-4" transmitted pictures of the Martian surface to Earth. To the amazement of many scientists, these pictures show crater-like structures similar to those on the Moon. Was this an accident? Or are circular structures the basic feature of the surface relief of all the inner planets? Indeed, they are found extensively on Earth as well. It is true that out planet tectonic processes such as erosion and filling with sediment play an important role; their action means that some circular structures have completely disappeared from the surface (sheared off or filled in, while others have developed to take their place). If the action of erosion were much less on Earth, as it is on Mars, or was practically absent as is the case on the Moon, would its surface also consist primarily of circular structures?

Uranium or Volcano?

At the end of the 1780's, the famous German astronomer Johann Schroeter was the first to suggest that all of the circular depressions on the lunar surface developed as the result of forces that originated in the core of the Moon itself. In 1824 the German astronomer Franz Groothuizen proposed another hypothesis which held that the craters were formed by the meteorites striking the Moon. Both of these hypotheses were purely speculative at the time they were made. Years have passed and knowledge regarding the perpetual companion of the Earth has increased rapidly.

Nowadays no one would be inclined to doubt that collisions of cosmic bodies with planets are possible. This is a fact that can be demonstrated /56 using the example of the Earth itself, where meteoritic dust, meteorites and meteorite craters are found in large numbers. Statistic on terrestrial meteors indicate that bodies with masses up to 1 kg are bombarding the Earth continuously. As the mass of the bodies increases their number decreases sharply, in approximately inverse proportion to the square of the mass ($N \sim 1/m^2$). How often do collisions occur between bodies of asteroid size with the inner planets? What is the maximum mass of the colliding body, and what is the maximum diameter of a meteorite crater? These questions are the subject of lively discussions at the present time.

According to the calculations of the well-known student of the minor planets, I. I. Putilin, the total number of asteroids (from the very largest Ceres D = 770 km) to those of the size of Adonis, inclusive (D = 1 km) is 140,000. Approximately 98.9% of them are in nearly circular orbits between Mars and Jupiter. Only 1.2% of them travel in highly elongated orbits due to some forces (possibly created by Jupiter and by mutual collisions); they travel beyond the limits of the Asteroid Belt and may approach the orbits of the larger planets: Mars, Earth, Venus and Mercury. Several of these asteroids (Eros, Hermes, Gamyede, Apollo, Adonis, Icarus, Geographos) come quite close to the Earth and Moon. However, the possibility of a collision with one of them with the Moon is extremely slight. For this to take place, it would be necessary for their orbits to intercept and for them to arrive simultaneously at the same point in space.

What would have happened if the asteroid Icarus had collided with the Earth on the June 14, 1968? We know that its diameter is 1.5 km and that its velocity relative to the Earth is 43 km/sec. Assuming that the density of its material is about the same as that of the Earth's core (3 g/cm^3), we find that its mass is 4.5 billion tons. A body with such mass would form a crater 100 km in diameter (on the basis of similarity formulas, derived from observations of large explosions on Earth). It is felt that even during /57 the entire history of the Moon (4.5 billion years) no more than 10 craters of such size could be formed, produced by the impact of asteroids. However, there are thousands of them on the Moon. It is true that other large bodies such as comets are also moving about in interplanetary space in addition to the asteroids. It is difficult to estimate the probability of their collision with planets. It seems to us, however, that it does not differ very much from the probability of a collision between a planet and an asteroid. This means that the large craters on the Moon are much larger than the bodies which could have formed them. It is true that some astronomers have suggested that the density of meteoritic matter in interplanetary space was much greater during the early stages of formation of the planets. It was at this time, they believe, that the enormous number of circular craters was formed, not only on the Moon and Mars but on the Earth as well.

What was the density of the material at the early stages of the formation of the planets? Could it have formed such an abundance of enormous craters, all the way to circular seas? It is impossible to give a definite answer to this question at the present time. In fact, there is no unanimous opinion regarding the origin of the Solar System. Why should we place a random process -- collision -- above tha laws of development of nature, when there is a large supply of circular structures of different sizes on Earth which are of endogenic origin? They could be completely analogous to different types of lunar and martian craters. Let us examine some of the mechanisms of formation of craterlike structures.

When gases explode in a magmatic chamber located at some depth beneath the surface pressures develop under certain conditions which are capable of piercing the superincumbent rock overburden to form a cylindrical channel and a crater-like depression at the surface. In the majority of cases, friable materials form a cone or a ringwall around the crater. However, if the gas explosions are very strong, ash and pumice are scattered far from the edge and form only a thin covering. The developing volcano then forms primarily an explosion cone; the depression of this kind is often referred to as a maar. The diameters of maars vary from 200 to 3,200 m.

If the gas explosion takes place in an intermediate magmatic chamber filled with kimberlitic magma, the cyclindrical channel which is formed fills with kimberlite and is called a kimberlite pipe (explosion pipe, diatreme). It is also evident at the surface in the form of a crater-like depression. It shape may differ, but is most often circular. The diameter is usually 20 to 800 m, but sometimes reaches 1.5 km (South Africa).

In volcanic regions one often encounters enormous depressions with a circular shape (calderas), 25 to 30 km in diameter. There are explosive calderas and calderas formed by collapse. The latter retained particularly large dimensions; they are formed as the result of the collapse of conical and scutellate volcanos, which occurs following evacuation of the volcanic chamber during particularly violent explosive eruptions and the resultant weakening foundation of the volcano. Calderas often have flat bottoms and steep inner walls. Volcanic activity may continue following the explosion,

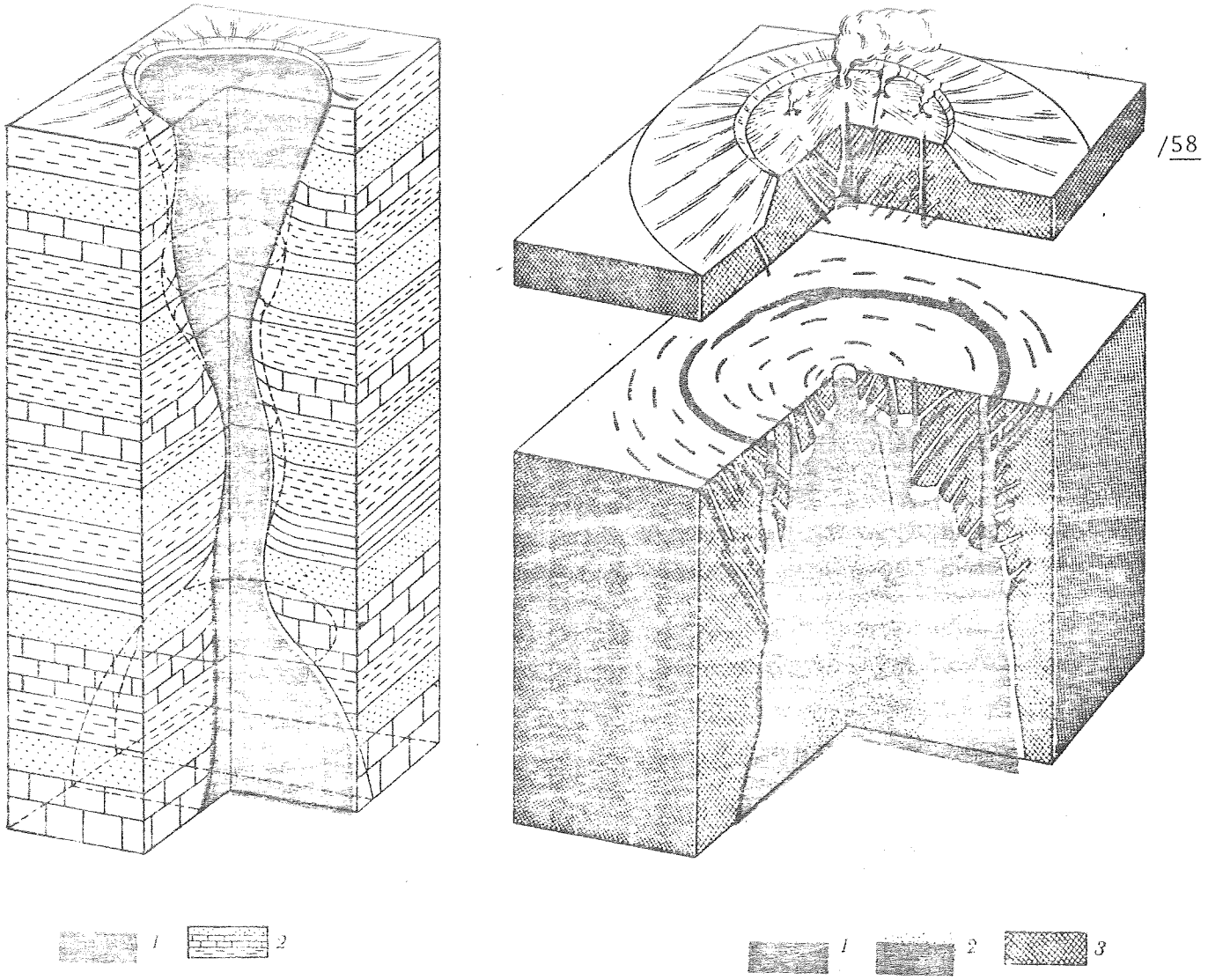
and in these instances a new volcanic structure begins to grow in the middle of the caldera. Sometimes it does not rise above the edges of the caldera and is then very similar to the central peaks of several types of lunar circular structures. There are many ancient calderas on Earth. An example is the severely erroded caldera in Central Kazakhstan, which are 8-28 km in diameter; some have a central peak and others do not.

Occasionally, as the result of severe cracking or areal eruptions from a volcanic chamber, an enormous amount of lava flows out. The pressure /58
in the chamber falls and there is a subsidence of the superincumbent block of the Earth's core along the faults. This forms enormous troughs, called volcano-tectonic depressions. It is in precisely this fashion that Lake Kurial in Kamchatka, measuring 13 × 10 km and 300 m deep, was formed.

In some instances, the principle phases of eruption or collapse are followed by extrusion of magma (i.e., the magma is forced out of the ground) along circular fractures. This form is the wall of the circular volcano-tectonic depression 120 km in diameter, which is known by the name of the Mogollon rhyolitic-ash mesa (located in the southwest part of New Mexico).

It has recently been suggested that many of the circular structures on the Moon which were formerly considered to be old craters that were eroded and filled with lava have a similar origin. For example, the British geologist G. Fielder talks of precisely the same origin for the circular structure called Flemstead R, 100 km in diameter, in the Oceanus Procellarum.

Magma extrusions can also develop without any connections with calderas and volcano-tectonic depressions. An explosion occurs at some depth as the result of excess pressure of gases in a magmatic chamber, resulting in the formation of cyclindrical and conical fissures in the earth's core. This results in an extrusion of magma which hardens on the surface to form cylindrical dikes and conical stratified intrusions. These resemble shallow craterlike structures. Structures of this kind have been investigated in /59
some detail in Scotland and northern Ireland. The diameters vary from 3 to 15 km; they are composed of basic, acid and neutral magmatic rocks. It



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Block Diagrams: Left -- Explosion Pipes; 1 -- Kimberlite Breccia; 2 -- Surrounding Sedimentary Rock; Right -- Calderas; 1 -- Cooling Magma; 2 -- Hottest Plutonic Areas.

is possible that the large (90 to 160 km) circular structures in the Precambrian volcanic complex of South Australia are of similar origin.

Indications of volcanic activity on the Moon have been recorded in recent years. A sensation was created in scientific circles by the announcement of the Soviet astronomer N. A. Kozyrev, who stated that on November 3, 1958 he recorded a spectrogram which indicated a glow produced by gases emerging from the central peak of the crater Alphonsus. If there is internal heat on the Moon, volcano-tectonic processes are certainly possible. In the opinion of a number of investigators, these processes probably played an important role in the formation of the surface relief of Earth, Mars and the Moon. However, one cannot deny the influence of cosmic bombardments. No doubt, some of the circular lunar structures are of precisely this origin. This is especially true for the numerous small craters with diameters on the order of 1 km, which are scattered at random over the lunar surface, and the craters with systems of rays, which range in size from less than 1 km to 100 km. Large foreign bodies also strike the earth.

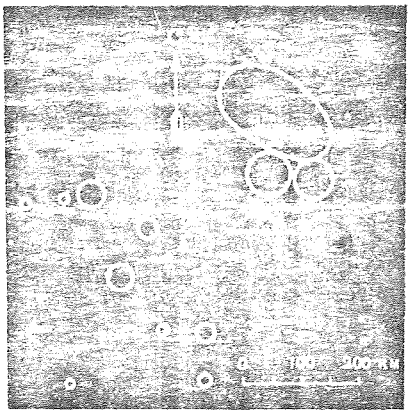
Meteorite Craters

Is there any way of making an approximate estimate of how many gigantic bodies could strike the earth and what such catastrophes could lead to? As a matter of fact, it is. The number of cosmic bodies of a given mass can be calculated by extending the features that have been recorded for small bodies to large ones (when the mass of a body is increased 10 times, its number is reduced 100 times). The diameters of the meteorite craters formed by collision can be estimated, as we have already mentioned, by using similarities derived from observations of large explosions on Earth. It is important in this regard to note the collision velocity of the meteorite with the solid surface of the planet. We will assume that this is equal /60 to 40 km/sec (since the collision velocity lies in the range from 11-72 km/sec).

We will find that 4 1/2 million craters the size of the one in Arizona (D = 1,200 m) are at Wolf Creek (D = 853 m) could have been formed over the entire surface of the Earth during the entire time of its existance (4.5 billion years); 100,000 the size of the Brent crater (D = 3,700 m) could have been formed.

Asteroids the size of Icarus could have struck our planet 10 times forming craters 80 to 100 km in diameter. The largest meteorite crater on Earth could have a diameter of 130 to 200 km, formed by a collision between the Earth and an asteroid having a mass of 10 to 35 billion tons.

This analysis shows that a significant number of meteorite craters must have been formed on Earth. We can only see a negligibly small number of them now, since they have been destroyed.



Plan of the Arrangement of the Meteorite Craters at Hamberry (Australia). The largest crater was formed by an explosion (it may consist of 2 combined craters), all the others were formed by impact.

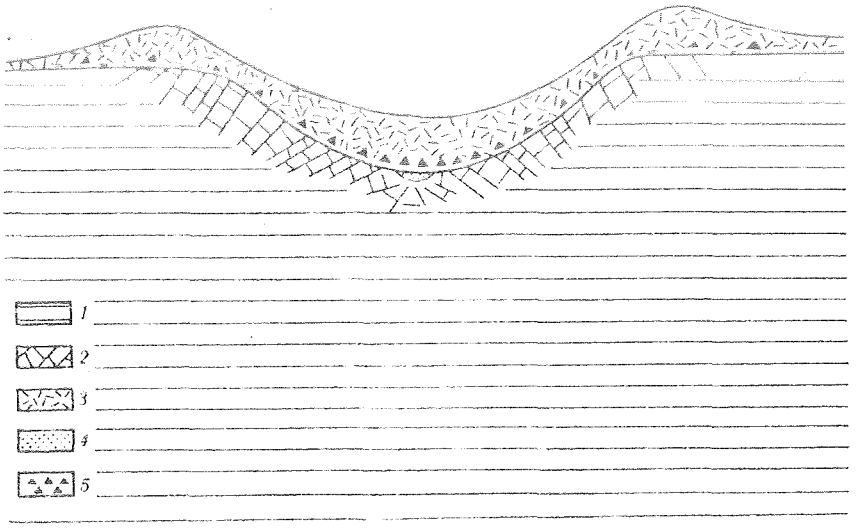


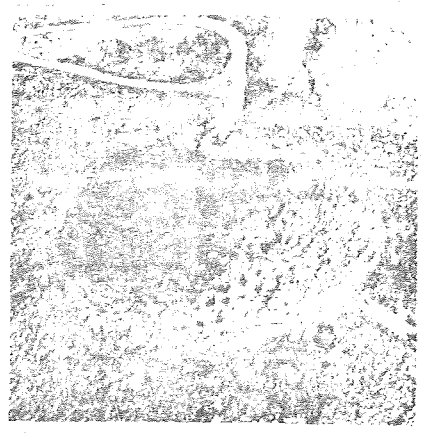
Diagram of an Impact Meteorite Crater: 1 -- Normally Occurring Strata Sedimentary Rocks; 2 -- Broken Cracks in Large Blocks of Sedimentary Rock, Upheaved Radially from the Center by a Shock Wave Propagating from the Point of Impact; 3 -- Detritus of Broken and Excavated Rock, Forming a Wall and Collapsing Back into the Crater Following Ejection; 4 -- Pit Indicating the Site of Impact of the Meteorite Rock Flour; 5 -- Meteorite Fragments.

At the present time, there are more than a hundred circular structures of different sizes on our planet, whose origin is quite difficult to explain from the geological standpoint. Undoubtedly many of them are of meteoritic origin and several new ones are added to their number each year.

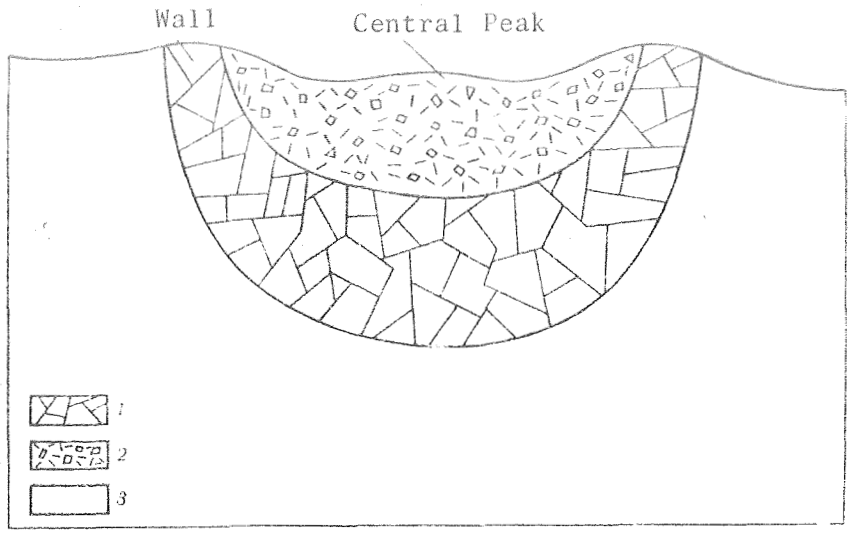
On the basis of a study of known meteorite craters and modern meteorite showers, Sikhote-Alinskiy (1947), Kunashak (1949), Prshibram (1959) and others, it has been determined that a meteorite usually breaks up on entering the Earth's atmosphere; every meteorite shower strikes an area which is roughly elliptical in shape (the scattering ellipse); the various pieces of the meteorite forms two categories of craters: explosive ones which are located in the forward part of the ellipse and are formed by the principle mass of the meteorite, flying with the remainder of its cosmic velocity; and the impact type, which occupy the middle portion of the scattering ellipse. As a rule, these fragments are distributed according to size. No craters are observed at the rear of the ellipse, but it is here that the small individual particles

of the meteorite shower fall (the weight can reach hundreds of tons and conventional meteor craters with diameters of 1 m or less may be formed).

Particularly complete data regarding the sizes, structure and conditions of formations of impact craters and meteorites have been obtained as a result of the study of the consequences of the fall of the Sikhot-Alinskiy meteor shower, which was undertaken by the Committe on Meteorites of the Academy of Sciences of the USSR and was conducted under the direction of Ye. L. Krinov. It was found that 24 impact craters with diameters from 8.5 to 26.5 m were formed in an area of 1.6 km^2. In addition to the craters, 176 pits and holes with diameters from 8 m to several cm were found. The impact craters were discovered to be very similar in their mechanism of formation, external appearance and structure to craters formed by the explosion of areal bombs. However, instead of being filled with fragments of the charges, they contain fragments of the meteorite as small as meteoritic dust. /61



Danny Boy Crater, Formed by the Explosion of an Underground Nuclear Charge in the Nevada Test Area (USA)
D ≈ 66 m.



Model of the Rottenberg Crater, Partially Based on Theoretical Studies and Partially on Observational Data for Atomic Explosions: 1 -- Crushed Rock, 2 -- Breccia, 3 -- Undisturbed Rock.

Explosive meteorite craters have a much more complex structure. It was shown as early as 1937 by the Soviet scientist K. P. Stanyukovich, then they are formed when the speed of collision of a meteorite with the hard surface of a planet exceeds 5 km/sec. A tremendous explosion results. In the first microseconds following the impact, the meteorite continues to move forward, compressing in its path the rock with which the impact occurred. At the same time, both the body and a portion of the medium undergo sharp heating due to the passage of a powerful shock wave through them, which develops at the moment of impact (its pressure is on the order of hundreds of thousands of atmospheres). The meteorite penetrates into the rock to a certain depth and when it stops completely, an explosion occurs, with instantaneous evaporation of the meteorite itself and a considerable part of the material around it. A cup-shaped depression, the meteorite crater, is formed at this spot. Its size is much greater than the size of the cosmic body and can reach tens of km in diameter.

As of the present time, seven explosive meteorite craters with diameters of 100 to 1,200 m have been found on Earth. There is no dispute

regarding their cosmic origin, since fragments of meteoritic material have been found in the craters and around them.

Careful geological examination of these meteoritic craters, experiments in modeling high speed shock, study of craters formed by underground nuclear explosions, experiments in determining the nature and behavior shock waves, and several theoretical concepts have provided scientists with several diagnostic features of explosive meteorite craters. They all owe their origin to the effects of a powerful shock wave propagating outward from the center of the explosion of the rockets. The pressure at the front of this wave can reach hundreds and thousands of killobars (1 kbar = 1,000 atm). There should be no reason to enumerate all the characteristic features of a meteorite crater; they have been described in full in the abovementioned article by I. T. Zotkin. I would like to mention only that the majority of them are found in different endogenic formations, so that it is usually very difficult to differentiate a meteorite crater from similar structures (especially ancient ones, formed hundreds of millions of years ago).

We have already mentioned that a circular flat shape is characteristic of many types of structures. The upraised rock strata may be formed by the upward movement of magmatic rocks or rock salt (magmatic stocks and salt domes are often circular in cross section).

Impactites are very similar to volcanic glasses which develop during rapid cooling of magma on the surface. The central peaks may be volcanic structures. The cones of rubble may be very similar to the geological formations known by the name of "cone within a cone" or "paper cone textures". /62

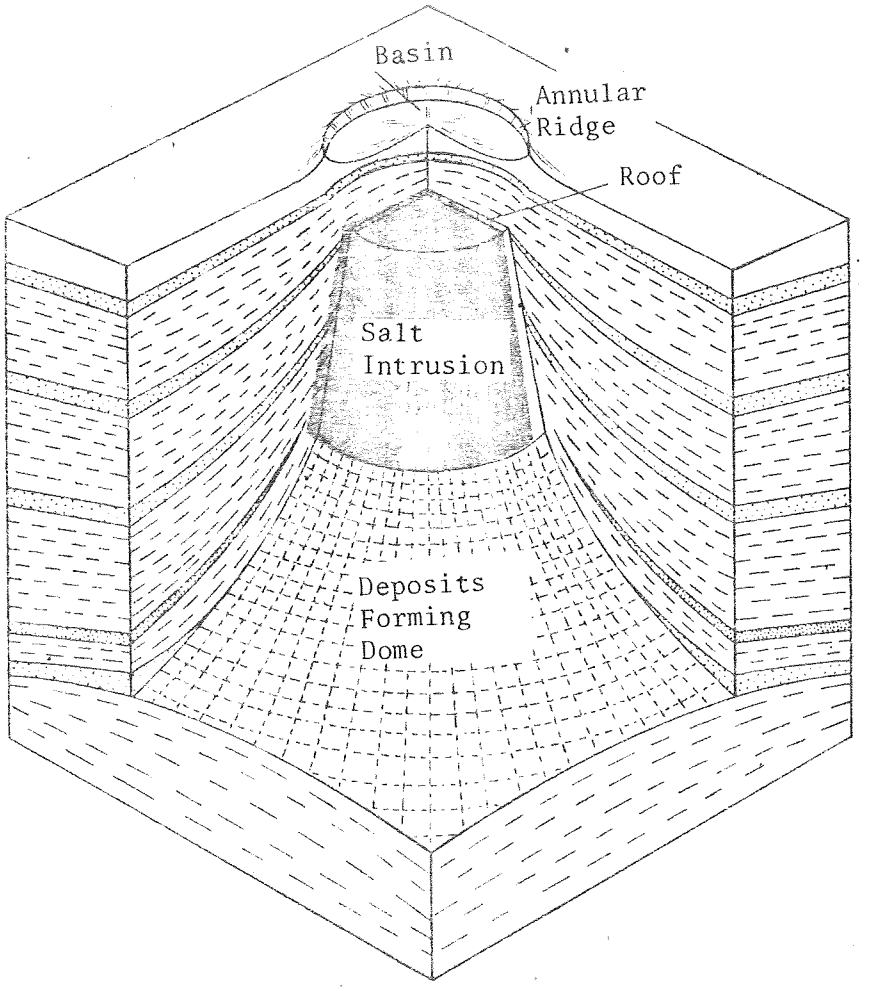
The minerals coesite stipoverite are more reliable prospecting signs of meteorite craters. The ranges of their stability are such that at the temperature of 100°C which is typical for zones of the earth's core near the surface, they can be formed at minimum pressures of 22 and 99 kbar, respectively. The possibility of developing comparable static pressures within the core are in the upper portions of the peridotitic layer have been proven to be impossible. On the basis of the isostatic equilibrium of the earth's core, the possible pressures at its base evidently cannot exceed

10 to 15,000 atm. However, the pressures which cause the transition of quartz to coesite may develop.

In the opinion of several investigators, at the moment of formation of an explosion pipe, when the gases explode in the magmatic chamber as the result of chemical reactions, the pressure can reach 60 to 65 kbars. However, coesite and stipoverite have never been found in these pipes, although the free silicon required for their formation is present, as indicated by the discovery of moissanite (SiC).

The pressures which cause the transition of quartz can also develop in powerful transverse stresses within the earth's core. The concentration of stresses within individual grains can then lead to pressures greater than 22 kbars. However coesite is not found along fault zones, although this does not exclude the possibility of its formation under these conditions. At the same time, however, formation of coesite has been detected in chemical and nuclear explosions; this mineral has been found in several other circular structures whose origin is best explained by a meteorite impact.

Thus the most reliable indication of the cosmic origin of a circular structure that has been found to date in our opinion, is its underground structure, especially the presence of breccia in the shape of a convexo-concave lense beneath the depression. This information can only be obtained by boring.



Block Diagram of a Salt Dome Showing Dome-shaped Upheaval of Sedimentary Rocks Around a Salt Intrusion and a Topographically Enveloped Basin with An Annular Ridge, Formed as a Result of Errosion as the Covering Strata at the Surface.

The following are captions to pictures not reproduced.

Caption for photograph on page 55 of foreign text:

Larion Mikhaylovich Shkerin, Scientific Associate of the Department of Comparative Planetology of the Department of Geology of the Academy of Sciences of the USSR. He is engaged in the study of terrestrial meteorite craters in an effort to explain the origin of the lunar and martian crater-like structures.

Caption for the two photographs on page 56 of the foreign text.

Upper picture: Portion of the lunar surface in the region of the South Pole. The enormous circular structure at the center is the walled plain Clavius (D = 375 km); Below and to the left of it is Maggini (measuring 240 × 90 km); Below and to the right is Longomontanus (D = 185 km).

Lower picture: Picture of the Martian surface by the automatic interplanetary station "Mariner 6" (through a red filter). An area measuring approximately 880 × 770 km is shown; the coordinates of the center are 345° d., 16° S. The distance from the camera to the surface is 3,440° km. One can see craters in different degrees of preservation, some of them with a central peak and partly polygonal outlines. At the right, below the center line, is an enormous crater approximately 250 km in diameter.

Caption for the photograph on page 57 of foreign text.

Region of the Sea of Clouds. Within its boundaries, we can see a large number of half-filled craters of different sizes. At the bottom center of photograph is the crater Pitatus (D = 100 km) half-filled with lava.

Caption for the two photographs on page 59 of foreign text.

Upper picture: Broken ring in the Oceanus Procellarum, known by the name Flemstead R. The photograph was taken by the "Orbiter-3" automatic lunar satellite on February 21, 1967. The point where the "Surveyor 1" made its soft landing on June 2, 1966 lies within the ring. The mountains in the north-east part of the ring (at the bottom right of he picture) were observed by the television camera aboard the "Surveyor".

Lower picture: Portion of the lunar surface in the region of the North Pole. The crater with the system of rays is Anaxagoras (D = 50 km). At the bottom center of the picture is the crater Plato (D = 110 km). The dark region between Anaxagoras and Plato is the Mare Frigoris.

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